THE GREATER VANCOUVER WATER DISTRICT – AN ECOLOGICAL INVENTORY APPROACH TO FIRE HAZARD ASSESSMENT AND TREATMENT FOR PROTECTION OF WATER QUALITY AND OTHER SECONDARY VALUES

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ABSTRACT

In 1992 the Greater Vancouver Water District began an extensive ecological inventory of its three watersheds (53,600 ha) that serve as the drinking water source for the Greater Vancouver Region. The focus of the inventory, which integrates physical and ecological information, was to provide watershed managers with a better understanding of the physical and ecological processes within the watersheds, to address concerns regarding management practices and water quality in the watershed and provide a basis for vegetation cover management planning. The inventory consisted of six integrated components, which included climate and hydrology, terrain inventory and sediment yield, ecosystem inventory, fire assessment, forest health, and development of a GIS based watershed model. As part of the fire assessment work an inventory system was developed and implemented to quantify forest fuels within the watersheds. Once the inventory was completed a comprehensive database was developed linking terrain, ecological, and forest fuel databases in an ARC/INFO GIS system. The GIS data was used to develop a forest fire hazard prediction and risk model that operates on a 200 year planning horizon. Model outputs identified current fire hazard conditions as well as changes in fire hazard related to forest succession over a 200-year period. The model was used to test management options, which included two levels of fire hazard reduction treatment and a control (no treatment) to assess the impacts on water quality and other secondary values over the 200 year period. Additionally, fire hazard data was linked through a disturbance matrix to fire severity (crown class removal and exposed mineral soil). This linkage allowed for an evaluation of the effects of treatment and no treatment on fire severity following a simulated burn, and the resultant impacts on sediment yield delivered to the reservoir.

Keywords: fire hazard, water quality, models, forest succession

INTRODUCTION

The GVRD watersheds, located north of Vancouver, British Columbia, Canada, comprise the Capilano, Seymour, and Coquitlam drainages which together cover 53,600 hectares. The primary use of these watersheds is to provide safe, clean drinking water to the Greater Vancouver Region.

During 1990 and 1991, the Greater Vancouver Regional District (GVRD) conducted a comprehensive and public review of the policies and operations of the Capilano, Seymour, and Coquitlam watersheds. During this review, a panel of independent technical experts made several recommendations to the GVRD Administration Board including the need for a detailed ecological inventory to collect data for developing a comprehensive, long-term land management plan to protect water quality in the watersheds. In 1992-93, an interdisciplinary team of specialists began the inventory with a pilot study in the Jamieson, Orchid, and Elbow drainages in the Seymour watershed. After refinement of the inventory procedures, the specialists completed the full ecological inventory of the Seymour, Coquitlam, and Capilano watersheds from 1995 to 1997.

The focus of the inventory was to provide watershed managers with a better understanding of the physical and ecological processes within the watersheds, to address concerns regarding management practices and water quality in the watershed, and provided a basis for vegetation management planning (Figure 1). The inventory consisted of six integrated components which included climate and hydrology, terrain inventory and sediment yield, ecosystem inventory, fire hazard assessment, forest health, and development of a GIS-based watershed model.

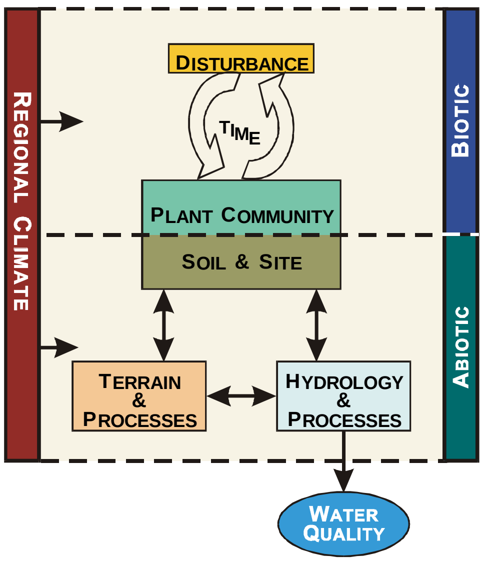

Figure 1. Integration of Watershed Processes in the Ecological Inventory Program.

This paper describes application of the inventory to fire management in the three watersheds and documents methods used in the ecological inventory and the ecological model for evaluating long-term, landscape-level fire management options for the watersheds.

Study Area

The GVRD watersheds lie within the Pacific Ranges of the Coast Mountains. The terrain is characterize by rugged topography, steep rocky slopes at higher elevations, and mountain peaks 900 to 1300 m abov the valley floor. Gentle to moderate slopes at low a d mid elevations are typically mantled by glacial deposits that range in texture from silts and clays to coar e gravels. Postglacial sediments, mostly coarse-textur d, have been deposited on gentle slopes by streams nd debris flows, and on steeper slopes by rockfall. L-andslides and erosion of glacial materials cause fine sediments to be washed into the reservoirs.

Ecosystems in the GVWD watersheds reflect the regional climate (wet, mild winters and cool summers) and local site conditions such as soil moisture regime, soil nutrient levels, soil parent material, and topography. The watersheds have been inventoried using the principles and methods of British Columbia's Biogeoclimatic Ecosystem Classification (BEC) system and Terrestrial Ecosystem Mapping (TEM) system. Vegetation in the lower elevations includes western hemlock, amabilis fir, western redcedar, Sitka spruce and some Douglas-fir tree species. With increasing elevation, yellow cedar and mountain hemlock become dominant tree species. In the cold, harsh climate of the highest elevations, vegetation consists of herbs, lichens, and scattered low alpine shrubs and trees. At the landscape level, the largest proportion of watershed forests are classified as old forest (i.e., greater than 250 years in age. Young and pole sapling forest stands are also present as a result of past fires and harvesting activities.

Forest ecosystems in the GVRD watersheds are representative of conifer-dominated temperate rain forests and coastal subalpine forests that stretch from central California to Alaska on the west coast of North America. The watersheds are dominated by ecosystems of the Coastal Western Hemlock Zone (CWH) and the Mountain Hemlock Zone (MH), with a very small area of the Alpine Tundra Zone (AT). The CWH is the largest biogeoclimatic zone in coastal BC, and stretches along the entire coast from Washington to Alaska. The MH zone occurs above the CWH zone along about the same latitudinal range. The AT zone is scattered along the coast above the MH zone.

Subzones and variants are lower categories of the zonal classification, and further refine regional climatic gradients and the distribution patterns of terrestrial ecosystems. Watershed forests occur in the Dry Maritime (CWHdm) Subzone, the Submontane Very Wet Maritime (CWHvm1) Variant and the Montane Very Wet Maritime (CWHvm2) Variant, the Windward Moist Maritime (MHmm1) Variant, the Windward Moist Maritime Parkland (MHmmp) Subzone, and the Alpine Tundra (AT) Zone. The CWHdm occupies low elevations in south coastal BC and only occurs in small areas of the most southerly, low elevation portions of the Capilano Watershed. The CWHvm1, CWHvm2, and MHmm1 variants dominate the majority of the area of the three watersheds, and these biogeoclimatic units are widely distributed along the BC coast. The MHmmp delineates the parkland subzone of the MH zone, which is transitional between forested ecosystems of the MHmm1 variant and non-forested ecosystems in the AT zone. Thus forest ecosystems present in the GVRD watersheds are typical of those that occupy large areas along the coast of BC.

METHODS

Fire Hazard Model Development

As part of the fire management component of the inventory a comprehensive fire hazard model was developed through a seven step process which is described as follows;

1. Establish sample plots (estimate sample plot fire hazard in the field and collect associated stand attributes).

2. Calculate descriptive statistics from sample plot data for estimated plot fire hazard.

3. Develop class breaks for each attribute and assign a model attribute score. The attribute class breaks were based on the results of step 2.

4. Establish model fire hazard class breaks for surface, crown, and total fire hazard based on the distribution of estimated fire hazard from sample plot data.

5. Supplement polygon database with derived fuel attributes (coarse fuels, fine fuels, ladder fuels, and height to live crown) based on descriptive statistics from step 2.

6. Compute surface, crown, and total fire hazard scores and associated fire hazard classes for all polygons in the watershed, using the attribute database (ecological, forest cover, TRIM, and derived fuel attributes) and the fire model.

7. Test model reliability.

Sampling Procedures and Plot Location

Plot location in the field was selected using aerial photos and forest cover maps. The sampling strata were the ecological polygons, defined by biogeoclimatic unit, structural stage, and site series. The objective was to achieve a representative sample across the range of ecological strata (based on biogeoclimatic unit, structural stage, and site series).

The objective of pre-locating the plots was to ensure that ecological stratum were represented proportionally. The range of ecological stratum was determined from the already completed Seymour ecological database. This information was subsequently updated as the Capilano and Coquitlam ecological inventories were completed. Ecological stratum that were inadequately covered, or not represented in the Seymour Watershed, were given additional representation in the remaining watersheds. Limited sampling was conducted within the Mountain Hemlock (MH) subzones since field reconnaissance of the area and a fire history study in the Capilano watershed identified only limited evidence of fire (the higher elevation and cooler, moister climate of these ecosystems significantly reduces the fire hazard).

Plots were established individually or as a plot transect depending on polygon location and access. A POC (point of commencement) was located at a known point on a map or air photo, which could be tied to individual plots or a line of plots. In an attempt to remove bias in plot location, an additional random distance, based on the size of the polygon, was travelled once the polygon was entered. A minimum of a 20 m buffer was maintained on obvious polygon boundaries or roads.

At each plot, a POC was established. From the POC, an equilateral triangle with 50 m sides was traversed. In small polygons (slide tracks and small ecological strata), the triangle sides were reduced to 30 m. A random bearing was recorded for the first side followed by a traverse of the triangle. Administrative data, as well as data for forest fuels, stand and ecological attributes, were collected at each plot. Photographs of the stand structure and forest fuels were taken to characterize each plot.

The loading of dead woody surface fuels greater than 1 cm diameter was assessed using the line intersect technique (Van Wagner 1968) along three 50 m or 30 m transects oriented at 60^0 to each other. The starting point and the direction of the first transect were randomly chosen. Fuel loads for each species present was estimated based on the line intersect data using information on wood relative density. An average decay class was determined for the fuel (Harmon et al. 1986). Only decayed material within classes 1 to 3 were considered as sources of surface fuel. Classes 4 and 5 were considered significantly decomposed and/or incorporated within the forest floor so as not to provide a significant source of fuel.

The loading of dead woody surface fuels (less than 1 cm in diameter) was estimated by destructively sampling one randomly located 1.0 m^2 plot located within 5 m of the plot POC at a representative location as per Blackwell et al. (1992). To obtain the sample, a 1.0 m^2 template was laid down and all material within the template was collected. Each sample was weighed after oven drying at 70^0C.

In addition to physical sampling, fuel load was visually estimated and assigned to one of the following fuel load classes: 0-5kg/m^2, 6-10kg/m^2, 11-20kg/m^2, and >20kg/m^2. To ensure accuracy in this assessment, crews were trained using visual aids and known fuel loads calculated for the Seymour Watershed to calibrate their assessment.

The overall forest fire hazard class was estimated in each plot for comparison with hazard values calculated by the forest succession model. Factors considered in this visual estimate included: fuel loading, ladder fuels, density, crown closure, species composition, snags, and topography.

Stand attributes were collected to provide additional data for the ecological classification database and to provide information for the forest fuels database. The duplication of model (ecological and stand) attributes collected by other sources was completed for confirmation purposes only. Slope, aspect, elevation, and slope positions were collected from field measurements. Structural stage was estimated from a visual assessment of age, structure, and forest cover data, and was confirmed with the ecological typing. Average height and height to live crown of dominant and co-dominate trees was visually estimated. Visual estimates were calibrated based on initial measurements of representative site trees. Crown closure was visually estimated.

Tree species composition was visually estimated for the four most dominant species. For the young forest and older structural stages, species composition was based on volume. For younger structural stages (initial, shrub/herb regeneration, and pole sapling), species composition was based on the number of stems per hectare within a fixed radius plot.

The tree density of dominant and co-dominant trees was collected in the Capilano and Coquitlam Watersheds. A fixed area plot was established with a size of 50, 100, or 200 m^2, which was dependent on achieving a minimum stem count of four trees. The same technique was used to record the tree density and species composition of suppressed and intermediate living trees and dead trees.

The continuity of fuels between the forest floor and the canopy (ladder fuels) is an important factor in the rate of spread of forest fires. Ladder fuels were evaluated using a visual assessment procedure developed within the watersheds. A 5-class scale was developed to rate ladder fuels and was calibrated with crew training, visual aids, and a group of reference stands. Reference stands were used for comparison. Ladder fuel estimates were based on stand density, branching pattern and retention, crown closure, and the fuel continuum between the forest floor and the upper tree canopy. This assessment could be expressed as a three dimensional view of forest fuels from above the ground surface to the top of the upper canopy.

Snags were inventoried using prism plots. At each apex of the fuel triangle, a 6 or 8 Basal Area Factor prism was used to tally snags by species and Diameter at Breast Height (DBH). Snags were classified as rough or smooth based on the presence and type of bark, presence of branches, shape, and condition. Where a snag was partially alive, a percentage of live crown remaining was estimated.

Ecological attributes were described according to "Describing Ecosystems in the Field" (Luttmerding et al. 1990), except where noted. For each site, the biogeoclimatic unit and site series were identified according to Green and Klinka (1994). A soil pit was dug at each plot POC. The soil moisture and nutrient regimes were assessed, and humus forms described according to Green and Klinka (1994). As part of this assessment, forest floor depth was also measured. Total shrub and herb cover was visually estimated, and primary and secondary shrub and/or herb species were identified. The plot was then examined for evidence of fire in the form of charcoal (in the soil, at the soil/forest floor interface, on snags, and on living trees) or fire scars on standing living and dead trees within the plot.

A total of 746 plots were sampled across the three watersheds Within all three watersheds sampling was primarily restricted to the Coastal Western Hemlock (CWH) zone. Sampling in the CWH zone was supported by fire evidence and fire history work, which demonstrated the majority of fires have occurred at elevations below 900 m., Limited sampling was conducted in the MH zone given its cooler/wetter climate and general lack of historical fire evidence. Fire history work conducted in the Capilano Watershed, indicated that some portions of the MH zone had been disturbed by fire, however, these areas were typically in lower elevations of the subzone occurring on steep southerly aspects where fires from lower elevations had burned up slope.

The largest proportion of sample plots (65%) within the CWH zone was concentrated in the CWHvm1, the dominant biogeoclimatic unit in the Capilano Watershed. The proportion of sample plots located in the CWHvm2 (25%) and CWHdm (3%) was lower. Less sampling intensity in the CWHdm was due to the small area of this subzone within the three watersheds.

Within the structural stage classification used in the three watersheds, plots were concentrated in shrub/herb, pole sapling, young forest, and old forest stands. Polygons classified as initial and mature forest were sampled at a lower intensity primarily due to the small area represented by these structural stages. Polygons within a deciduous stand successional pathway (SSP), classified as pole sapling deciduous and young forest deciduous, were considered to have a low to very low hazard and were only sampled to establish a baseline for substantiating model attributes and to verify a low hazard assessment. Biogeoclimatic unit, structural stage, and site series summarized the plot data.

Fire Hazard Model

The fire hazard model is a component of a larger spreadsheet-based watershed model developed for the GVRD to assist in long-term management of the watershed. The watershed model utilizes the data collected through the ecological inventory to forecast expected consequences of management action (or inaction) in terms of forest succession, fire and health hazards, and mean annual fine sediment delivery to the Capilano, Seymour, and Coquitlam reservoirs. It can also forecast these same results for scenarios involving landscape-scale disturbances in the watersheds such as fire or severe defoliator outbreak. All model inputs and outputs can be exported to GIS for graphical presentation.

The model is made up of several distinct components (Figure 2). For all area-based data handling and calculation purposes, the watersheds are subdivided into polygons. Polygons are defined in the GIS as areas of similar ecological and terrain attributes. Some additional elements of the database such as roads, streams and gullies are represented in the database and models as line segments.

The general operation of the model begins with input of the ecological inventory data to all submodels. The forest succession model is used to advance the age of

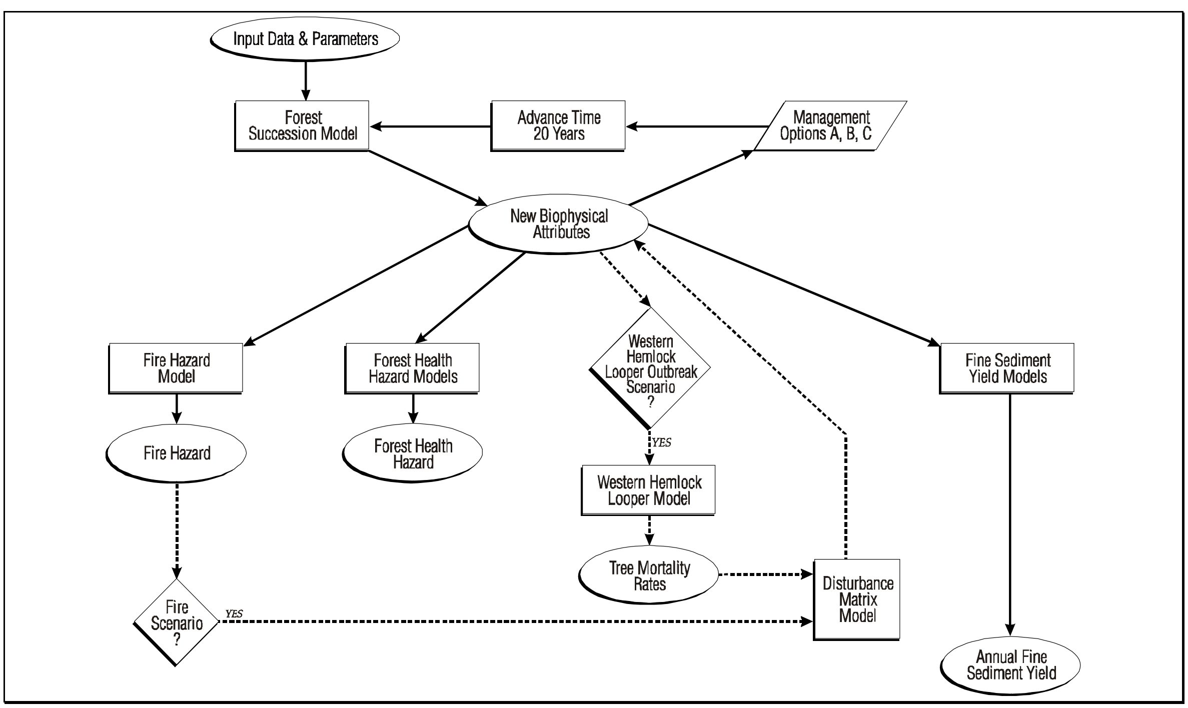

Figure 2. Watershed Model Schematic Diagram.

the forest by 20 year steps, and to output all related ecological attributes, which are again used by other submodel components in their calculations. Management strategies and/or disturbance scenarios (i.e., fire) can be simulated at any time step of the model.

The fire hazard model estimates the total fire hazard for each polygon as the sum of three separate components – surface fire hazard, crown fire hazard and topography. This structure allows stratification of the type of fire hazard in the stand (crown vs. surface), a feature that is useful for determining the most appropriate treatment strategy. Each component of the fire hazard rating is assigned based on information included in the ecological inventory database. Specific attributes for each hazard component are:

- *surface hazard*: fuel load, fine fuel load and site series;

- *crown hazard*: crown closure, height to live crown (HLC), density, species, ladder fuels and snags;

- *topography*: slope, elevation and aspect.

For each of these twelve attributes, a range of possible scores is developed that equates to high (1.0), medium (0.7), low (0.3) or zero (0.0) hazard. The twelve individual scores are then summed to derive a sub-component hazard score, and then a total fire hazard score for each polygon (i.e., to a maximum score of 12.0). A range of five hazard classes is used to designate these scores as very low, low, moderate, high or very high.

The fire hazard model is stepped through time in 20-year increments following the pathways of the forest succession model. Polygon fire hazard is updated in each time step by recalculating the fire hazard score, based on assignment of ecological and stand attributes, as it changes over time.

Slope, aspect, and elevation are unique values for each polygon, which were calculated within the ARC/INFO GIS system using TRIM data and assigned as polygon averages. Fuel loading, fine fuel loading, HLC and ladder fuels were derived based on the sample plot database and the associated ecological attributes (biogeoclimatic unit, variant, site series, and structural stage) of a given polygon at a given time.

Site series was assigned from the ecological database. Crown closure, density, and species composition were assigned to individual polygons from forest cover data. Snags were assigned from the forest cover database and are currently a static value that does not change over time.

The fire hazard class designation is assigned to all polygons within the GIS database. A default fire hazard was assigned to a number of specific zones, site series, and non-vegetated areas within the GIS database. This default hazard classification was supported by the fact that these areas provide barriers to fire and could therefore be considered as natural firebreaks, which have a relatively low probability of burning and hence could alter fire behaviour (Loope and Gruell 1973; Heinselman 1973; Romme and Knight 1981).

There has been limited work conducted on the assessment of stand and landscape-level fuel and associated fire hazard. Models of fire behaviour have typically focused on ignition and spread processes within a uniform fuel complex (i.e. fuels described qualitatively) without incorporating stand and landscape variation (Turner and Romme, 1994). The model developed in this project is quantitative in approach, with the exception of site series and ladder fuels, and assesses hazard on the basis of accepted quantitative measures that vary both within and between stands at a landscape level.

Sample plot data were used to determine which variables most influenced fire hazard and the critical point at which the importance of each variable changed. Means and standard errors were calculated for each potential fire hazard variable by the fire hazard estimate for plots in the CWH zone. Box plots comparing the median and range of fire hazard variables within the estimated fire hazard classes for the CWH zone were compared. Data for all watersheds were evaluated to maximize the sample size.

For individual model variables obtained by sampling or from the forest cover database, range determination equating to high, medium, low, and zero was carried out by reviewing polygon summaries and descriptive statistics for each of the individual attributes. The slope breaks were determined using empirical relationships established by Van Wagner (1977a). Aspect ranges in degrees were delineated as northeast (low), southeast and west (medium), and south (high). Elevation ranges generally follow biogeoclimatic subzone/variant boundaries and were supported by the fire history study.

Class breaks for fuel loads were established based on descriptive statistics from sample plots established in the three watersheds. Ranges were compared and validated with a number of studies found in the literature (Albini et al. 1995, Reinhardt et al. 1991, Feller 1988, Little et al. 1986, Brown and Bevins 1986, and Pickford et al. 1980). A fuel loading below 10 kg/m^2 was considered low and was assigned a model weighting of 0.3. Typically, loadings below this limit were discontinuous, and unevenly distributed. Loadings between 10 and 15 kg/m^2 were assigned the middle weight of 0.7 based on more evenly distributed loading and slash depth. Loadings exceeding 15 kg/m^2 were generally continuous in nature and composed of heavy fuel of significant depth.

The class breaks established for site series were based on relative moisture regime. In general, site series correlated with hazard classification. Relative soil moisture regime (SMR) uses eight classes to rank the relatively driest soil (0) to the relatively wettest soil (7) within a particular biogeoclimatic subzone or variant (Green and Klinka 1994). The rational for the use of site series as a model variable was based on the relationship of soil moisture to the moisture status of vegetation and downed and dead woody fuels. Studies by Samran et al. (1995) and Johnston and Woodard (1985) suggest that precipitation alone may not be the only factor affecting fuel availability and fire behaviour in some forest types. This is particularly true on mid to lower slopes in the watersheds, which receive moisture inputs as seepage throughout most of the growing season.

Crown closure, HLC, and stand densities were all quantitative measures describing stand structure. One or all of these variables have been used in other hazard and or modelling studies to describe crown fire potential (Van Wagner 1977b, Ross et al. 1981, FCFDG 1992). Van Wagner (1977b) described the relationship between the HLC and its importance as a conduit that enables surface fire intensity to develop beyond a threshold where fire is able to move into a crowning phase. Additionally, Van Wagner (1977b) describes crown bulk density as important in the behaviour of crown fires. In the development of this model, the use of crown closure, density and qualitative measure of ladder fuels all combine to describe crown characteristics of the fuel complex and their relationship to crown fire hazard.

These variables are standard inventory attributes and can be used to assess other values such as biodiversity and wildlife habitat. This approach differs from other fire behaviour models (FCFDG 1992) which describe forest structure qualitatively. Quantitative measures could easily be assessed in the field, and allowed for calibration within all structural stages regardless of age and ecological classification. The other advantage of quantitative measures was the ability to adjust the model breaks for any given variable if results were deemed inaccurate.

The model attribute classes were calibrated with visual hazard assessments done in the field and with model outputs from the Capilano Watershed. Final classes were based on these assessments, professional judgement and experience gained from similar modelling work conducted for the development of fire management plans in Bowron and Robson Provincial Parks (Blackwell et. al. 1996, a, b).

Basic Model Assumptions and Limitations

The model relies on the assignment of mean values for surface fuel load and HLC by biogeoclimatic unit, structural stage and site series, and ladder fuels by structural stage only from the population of sample plots having the same ecological attributes. Assumptions were made when these attributes were assigned to polygons without an available plot sample. If no equivalent set of plot sample attributes were available, the next most suitable attributes within the database were chosen in order to assign values of similar ecological criteria.

Data were collected as a point sample within an ecological polygon. This implied that the area was uniform in site series. Most polygons within the watersheds are composed of a complex of more than one site series. Attributes were assigned based on the dominant site series. For example, a polygon with the site series classification of 60% 05 and 40% 01 would be assigned the attributes for site series 05.

The results of the model are summarized on a landscape (forest) level (Figure 3). This means that stand specific comparisons to model outputs may differ on a polygon by polygon basis, however the relative distribution of hazard for a given set of ecological attributes will be accurate. The application of the fire hazard model should be restricted to higher level planning. Once watershed management plans are developed, further detailed stand and operational planning will be required.

Model Reliability and Testing

The forest fire hazard model is a numeric model with distinct breaks in the crown, surface and total fire haz-

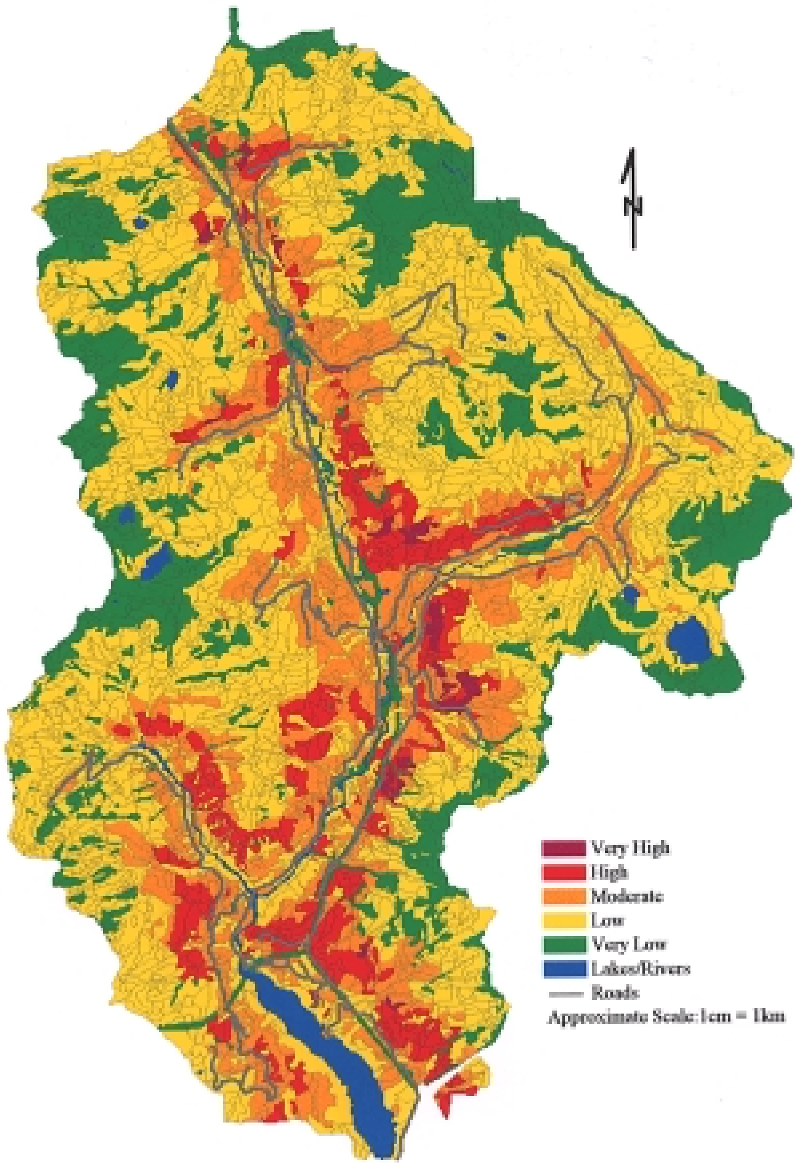

Figure 3. Total Fire Hazard, Year 0.

ard ratings as well as in the assignment of individual model variables. There are two levels of testing and reliability. Firstly, the sample plot data was used to calculate hazard of the sampled polygon and this was compared to the field estimate of fire hazard. The second level of testing was a check of model reliability using independent field visits.

Within the sample plot population, a hazard was computed using the model and the sample plot attributes, and this was compared with the fire hazard that was estimated visually at each plot. Not all variables were collected at each sample plot so this comparison was based on 430 of the 664 plots sampled in the CWH zone. The correlation between visual hazard estimates and computed model hazard estimates from sample plot scores was correct or within 1 hazard class for 95% of the sample plots tested.

As an additional check of model reliability, a sample of 118 polygons in the Capilano was selected to test model accuracy in hazard prediction. Check polygons were selected in proportion to their occurrence within the population of biogeoclimatic unit and structural stage combinations. Model fire hazard predictions of polygons that had not previously been sampled were selected and compared to an unbiased visual hazard assessment. The results of this phase of model reliability testing demonstrated that fire hazard was correctly predicted for 82% of the polygons checked.

APPLICATION OF THE FIRE HAZARD MODEL

Treatment Development and Fire Scenario

As a component of analysis of the ecological inventory data and it's application to management planning, modelling related to fire hazards focused on addressing three questions:

- How could risks to water quality be reduced through treatment of stands with an identified fire hazard?
- What would be the estimated impact on water quality (measured as Annual Fine Sediment Yield [AFSY]) of a significant fire in the Capilano Watershed in the absence of fire hazard reduction treatments?
- What would be the estimated impact on water quality (measured as AFSY) of a significant fire in the Capilano Watershed if stands with identified fire hazards were treated to reduce hazard?

To address these three questions a series of analytical models were developed utilizing the predictive capabilities of the forest succession model, sediment yield models, and fire hazard model.

Treatment options focused on providing decision-makers with the broadest range of possible results based on sound scientific knowledge gained from the ecological inventory.

Three fire management treatment options were developed. Treatment strategies were developed that targeted stands with very high, high, and moderate fire hazard classes on a range of structural stages and terrain types Targeted stands were identified using the results of the fire hazard model.

Option A

The objective of this option is reduction of stand level fire hazard on approximately 3,931 ha or (20%) of the Capilano Watershed over a 20-year timeframe. This strategy is considered the most aggressive of the three options.

In mature and old forest stands, partial cutting (basal area reduction of between 30-40%) and patch cutting (openings restricted to two tree lengths) are the proposed silvicultural systems that will be employed to treat identified stand level fire hazard. Where possible, features important for old growth and critical wildlife habitat will be maintained. The maintenance of structural attributes will include, but are not limited to, large diameter trees, coarse woody debris, identified wildlife trees, and maintenance or enhancement of tree species diversity.

In young forests, thinning from below (i.e. removal of intermediate and suppressed trees) will be the primary method of stand hazard reduction. Alternatively, a patch cut silvicultural system (openings restricted to two tree lengths) will be utilized on sites with a forest health issue posing a significant threat to water quality, or undesirable species and/or stand structure attributes.

In pole sapling stands, juvenile spacing combined with pruning will be the prescribed treatment method used to reduce identified fire hazard. These stands have high stand densities and crown closure with crowns that persist to the forest floor.

The overall focus of proposed treatments in Option A are a reduction in tree density, crown closure, ladder fuels and an increase in the height to live crown. Typically, these types of treatments may cause a short-term increase in surface fuel loading. These treatments will result in stands with lower total (surface and crown) fuel loadings and a more discontinuous fuel complex.

Option B

The objective of this option is reduction of stand level fire hazard on approximately 1,670 ha or (8%) of the Capilano Watershed over a 20-year timeframe. This option is considered a less aggressive hazard reduction strategy, compared to Option A, and is restricted to a smaller area with treatments limited to younger forests on stable terrain.

Treatments would be restricted to pole sapling and young forest structural stages with very high, high, and moderate hazard classes. Treatments would be implemented as described in Option A.

As discussed in Option A, the focus of treatments will be to reduce stand level fire hazard through a reduction of tree density, crown closure, ladder fuels, and an increase in the HLC. The objective is to increase the discontinuity of the fuel complex in identified hazard classes, while preserving or enhancing significant biodiversity or structural attributes of these stands.

Option C

This can be classed as a no treatment option and in some respects, represents a benchmark by which other analysis options can be compared. The objective of option C is to allow for advancement of forest succession processes without intervention. Natural disturbances such as fire will be considered a threat to water quality and will continue to be aggressively suppressed as in Options A and B.

As discussed above, the objective of treatment is a reduction in the quantity and continuity of the fuel complex. Through fuel reduction treatments such as thinning, it is expected that potential fire severity may be altered resulting in a greater degree of patchiness in burn severity that may reduce the effects of fire on streamflow and water quality (Knight and Wallace 1989). The most appropriate treatments for a given structural stage and stand type are site-specific, which typically requires a significant amount of planning. Outputs generated from treatment themes produced in Options A and B are modelled at a landscape level. Treatments were implemented at the polygon level and modelled by altering stand attributes to achieve target attributes associated with low fire hazard conditions.

FIRE HAZARD RESULTS

Results Overview

There are currently 5,458 hectares of forests or 27% of the landscape within the Capilano watershed rated within the moderate, high and very high fire hazard classes of concern. The entire area is within the Coastal Western Hemlock biogeoclimatic zone. The largest portion of the area – 2,937 hectares – is within the Young Forest stand structural stage, and the next largest portion – 1,764 hectares – is within Old Forest (Figure 4). Option A shows the reduction of fire hazard area possible through intensive silviculture intervention. Of the original 5,458 hectares of fire hazard area, 3,931 hectares were treated. The remaining 1,527 hectares were excluded from treatment since they either fell on unstable terrain, or were considered rare or endangered ecosystems in the Mature to Old Forest stage. The significant fire hazard area reduction achieved by year 20 is followed by a slight and gradual increase in fire hazard area across the watershed as additional untreated areas currently in the initial stage succeed into the pole sapling, higher hazard stage. Further forest succession reduces these and other areas to lower fire hazard ratings. In the long term (year 200), fire hazard area across the landscape can be reduced to 1,877 hectares, which is 34% of the original fire hazard area and 10% of the total watershed area.

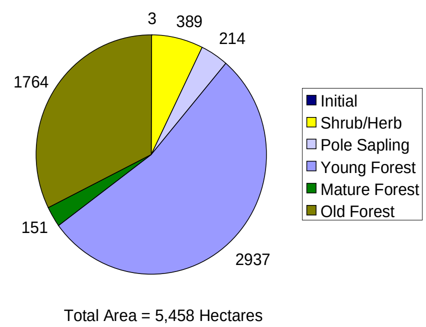

Figure 4. Fire Hazard Area within Each Stand Structural Stage at Year Zero.

Option B shows the reduction of fire hazard area possible through an intermediate level of silviculture intervention. Of the original 5,458 hectares of fire hazard area, only 1,670 hectares were treated. The remaining 3,788 hectares were excluded from treatment. These include unstable terrain, as well as *all* Mature and Old Forest areas. As expected, the overall fire hazard area reductions are less than under Option A by year 20. Beyond year 20, forest succession causes total fire hazard area to follow a pattern over time similar to Option A. In the long term (year 200), fire hazard area across the landscape can be reduced to 3,441 hectares, which is 63% of the original fire hazard area and 17% of the total watershed area.

Option C shows the effect of allowing natural succession to progress without silvicultural intervention. Generally there is a slow trend toward lower fire hazard area in the Capilano watershed as the forests succeed toward the older forest classes. In the long term (year 200), fire hazard area across the landscape reduces naturally to 3,911 hectares, which is 72% of the original fire hazard area and 20% of the total watershed area.

Fire Hazard Area and Stand Structural Stage (SSS)

The fire hazard areas differ among management options both in terms of absolute area and in terms of stand structural stage class (Figure 5). This is most evident at year 20 after management prescriptions have been implemented under options A and B.

Under Option C at year 20, the total fire hazard area is largest at 5,112 hectares, with the largest portion of this being young forest (2,960 hectares), and the next major portion being old forest (1,632 hectares). The total area of old forest hazard area is unchanged from current conditions.

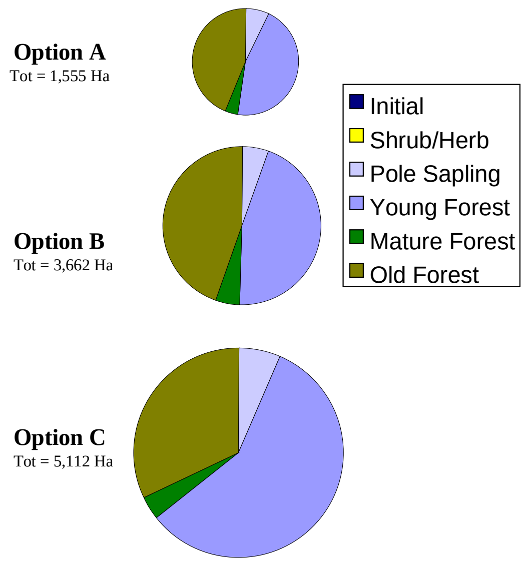

Figure 5. Fire Hazard Area within Each Stand Structural Stage at Year 20.

Under Option B at year 20, the total fire hazard area is reduced to 3,662 hectares, with the absolute area of old forest remaining the same as in Option C (1,632 hectares). Young forest hazard area is reduced to 1,658 hectares giving it an equal share of the total. Again, the total area of old forest hazard area is unchanged from current conditions.

Under Option A, all forest types are reduced in hazard resulting in the smallest total area at 1,555 hectares. Young and old forest types account for 708 hectares and 680 hectares respectively.

Summary of Key Points

- Left alone to follow natural forest succession (Option C), forests in the Capilano Watershed will follow a slow, long term trend toward lower fire hazard condition.

- Through active silviculture intervention (Options A and B), an immediate reduction in the current total fire hazard area in the Capilano Watershed can be achieved.

A more detailed discussion of the methods, model development and analysis of the ecological inventory program is contained in the Annex to the Analysis Report (Acres International et. al. 1999).

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